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Accidental Risk Assessment on Atmospheric Distillation Column in Oil Refinery

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Major accidents in industries brought the need of risk management systems specific to processes and regulative implementations. Several methods have been developed to assess risks of industrial accidents. Hazard and operability study (HAZOP), fault tree analysis (FTA), event tree analysis (ETA), control lists and hazard index are examples. One of the well-known regulatory documents designed to ensure that risks are assessed and minimized to the extent practical for this industry is the Seveso Directive. After the accident in 1976, EU directives were adopted and revised in the years 1982, 1996 and 2003.
In this study, "Accidental risk assessment methodology for industries (ARAMIS)" has been applied together with HAZOP on an atmospheric distillation column and column inlet-outlet lines which are located in the atmospheric distillation unit of TUPRAS Kırıkkale petroleum refinery. During the study, two sub-methods of ARAMIS were performed. One was the identification of major accident hazards (MIMAH), and the other was the identification of reference accident scenarios (MIRAS). MIMAH consists of FTA, ETA and Bow-Tie steps. These steps were used to define critical events and dangerous phenomena which may impact safety equipment. Following MIMAH, MIRAS was used to define the frequency of the critical events that may occur. To provide the continuity of the method, barriers were defined and the performance and reliability of the barriers were evaluated. The resulting accident Frequencies and the class of the consequences of the dangerous phenomenon were determined. Finally, reference accident scenarios (RAS) were evaluated by mapping results onto the risk matrix. HAZOPs were applied to strengthen the root causes of the fault tree analysis after the MIMAH step.
This study constitutes as a reference risk assessment study for the atmospheric distillation column. It underlines the main risks, and identifies hazard sources and the barriers to minimize the risks.

1. Introduction

Recent major industrial accidents that happened in the world (Enschede-2000, Toulouse-2001, Lagos-2002) have increased the interests of governments, regulators, and private companies in the industry to risk assessment methodologies (Dianous V. et al., 2006). In the meantime, the need to understand underlying causes of these accidents has led various studies in this field. One of these studies is Accidental Risk Assessment Methodology for Industries (ARAMIS) developed with the support of Fifth European Community Framework Programme under the guidance of Seveso II Directive. ARAMIS Project defines a methodology for the risk assessment (Delvosalle et al., 2004a).

2. Methodology

A primary objective of the ARAMIS Project is to develop a new risk assessment method through combining strengths of various risk assessment methods typically implemented in EU producing effective results (Turkish Ministry of Labour and Social Security, 2012).

2.1 Methodology for the Identification of Major Accident Hazards (MIMAH)

MIMAH is a method aiming to identify potential major accident hazards in a process industry before they happen. The methodology is based on the bow-tie diagram tool applied for the hazardous equipment. All

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outputs of MIMAH constitute the basis for the MIRAS methodology, which aims to define reference accident scenarios in the second phase of the ARAMIS Project. An outlook of the MIMAH approach is given in Figure 1 below (Andersen et al., 2004).

2.2 Methodology for the identification of reference accident scenarios (MIRAS)

MIRAS approach aims to determine reference accident scenarios among all potential accident scenarios through converting the qualitative analysis of MIMAH into a quantitative one. The basic objective of the methodology is to determine the reference accident scenarios for which severity index is to be calculated. Figure 1 below provides an outlook of MIRAS methodology (Andersen et al., 2004).

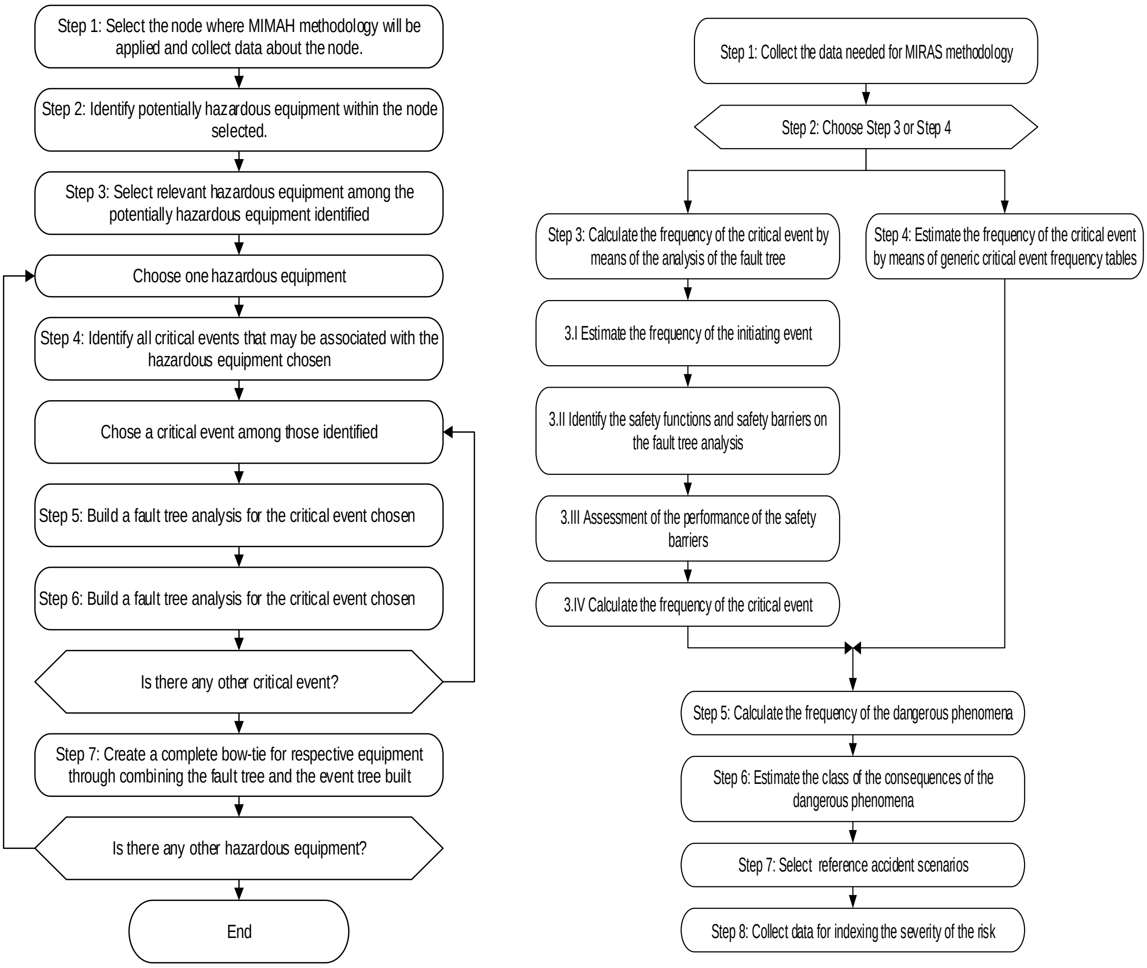

Figure 1: Flowcharts of MIMAH and MIRAS methodologies (Andersen et al., 2004).

3. Studies Performed with ARAMIS Project

3.1 Studies Conducted Applying Methodology for the Identification of Major Accident Hazards (MIMAH) of ARAMIS Project

All the potential major accident scenarios which can occur in the defined area were defined with MIMAH.

3.1.1 Collecting the data needed, identifying potentially hazardous equipment in the plant and choosing a particular hazardous equipment

Data was collected about all equipment on the site. As operating temperatures and pressures of the equipment and the substances contained inside respective equipment in the site selected for the study do not significantly vary, potentially hazardous equipment may not be identified on the basis of the data collected about the operating conditions and the load of the equipment. The correlation suggested by ARAMIS project for selecting hazardous equipment among potentially hazardous equipment is based on the boiling point of the substance (payload) inside the potentially hazardous equipment. However, as crude oil is a mixture, it does not have a precise fixed temperature for boiling but boiling temperature range. In such a case, the methodology suggested in ARAMIS Project becomes inapplicable. No particular hazardous equipment could be identified; therefore, the risk assessment methodology of ARAMIS Project was applied step by step to all equipment existed in the study site (Delvosalle et al., 2004b).

3.1.2 Identifying the critical events associated with each hazardous equipment selected

Potential critical events associated with all equipment existed in the study site were determined through applying a four-step matrix. (Delvosalle et al., 2004c). This four-step matrix comprises the equipment, the status of the substance inside the equipment and the critical event.

Table 1: Possible critical events in pipe line that carries heavy fuel oil from the atmospheric distillation column to the scrubber column

	Line carrying heavy fuel oil	Liquid	Pipe line and Liquid phase
CE1 Decomposition			
CE2 Explosion			
CE3 Materials set in motion (by air)			
CE4 Materials set in motion (by a liquid)			
CE5 Start of a Fire(LPI)	X	X	**X**
CE6 Breach on the shell in vapour phase			
CE7 Breach on the shell in liquid phase		X	**X**
CE8 Leak from liquid pipe	X	X	**X**
CE9 Leak from gas pipe	X		
CE10 Catastrophic rupture		X	
CE11 Vessel collapse		X	
CE12 Collapse of the roof		X	

Using the matrix above, Start of a Fire (CE5) and Leak from Liquid Phase (CE8) were identified as potential critical events that may happen in heavy fuel oil transportation line (see Table 1).

3.1.3 Creation of fault trees, event trees and bow-tie diagram for each critical event

A fault tree (Debray B. et al., 2004, NASA Publication, 2002) and an event tree (Delvosalle C. et al, 2004d, IEC 62502, 2010.) were created for each critical event that may happen in each hazardous equipment. A bow-tie diagram was created by combining fault tree and event tree analyses (Delvosalle et al., 2004a). A part of the Bow-tie diagram for the critical event of leak from liquid phase in pipeline concerned is in Figure 2 below.

3.2 HAZOP Risk Assessment Methodology

HAZOP process hazard analysis was applied for the same study site to support the root causes defined in fault tree section of the Bow-tie diagram and to examine the root causes in the line of another risk assessment method. The results of HAZOP process hazard analysis and the fault tree analysis of bow-tie diagram were reinterpreted. HAZOP study is given in Table 2.

3.3 Methodology for Identification of Reference Accident Scenarios

3.3.1 Collecting needed data

After creating bow-tie diagram, data needed for identification of reference accident scenarios were collected. Information collected includes safety barriers, the performance of safety barriers detected, retention time passed after referring to the safety barrier and probability of failure on demand (PFD) of the safety barrier which will be assessed in event tree section of the bow-tie diagram (IEC 61882, 2003).

Table 2: Sample HAZOP Analysis for critical event of leak from liquid phase in pipe line carrying heavy fuel oil from atmospheric distillation column to the scrubber column

Line No	Guide Word	Keyword	Dangerous Deviation	Possible Causes	Result	Existing Measures	Action Required
Line	More	Pressure	High Pressure	1100-LIC 070 and 1100-LV 070 fault	Pipe leak due to overpressure as a result of closing the valves on the line connected to the scrubber column	None	Regular trainings for the operators, developing maintenance procedures, placing another cascade type LIC and LV

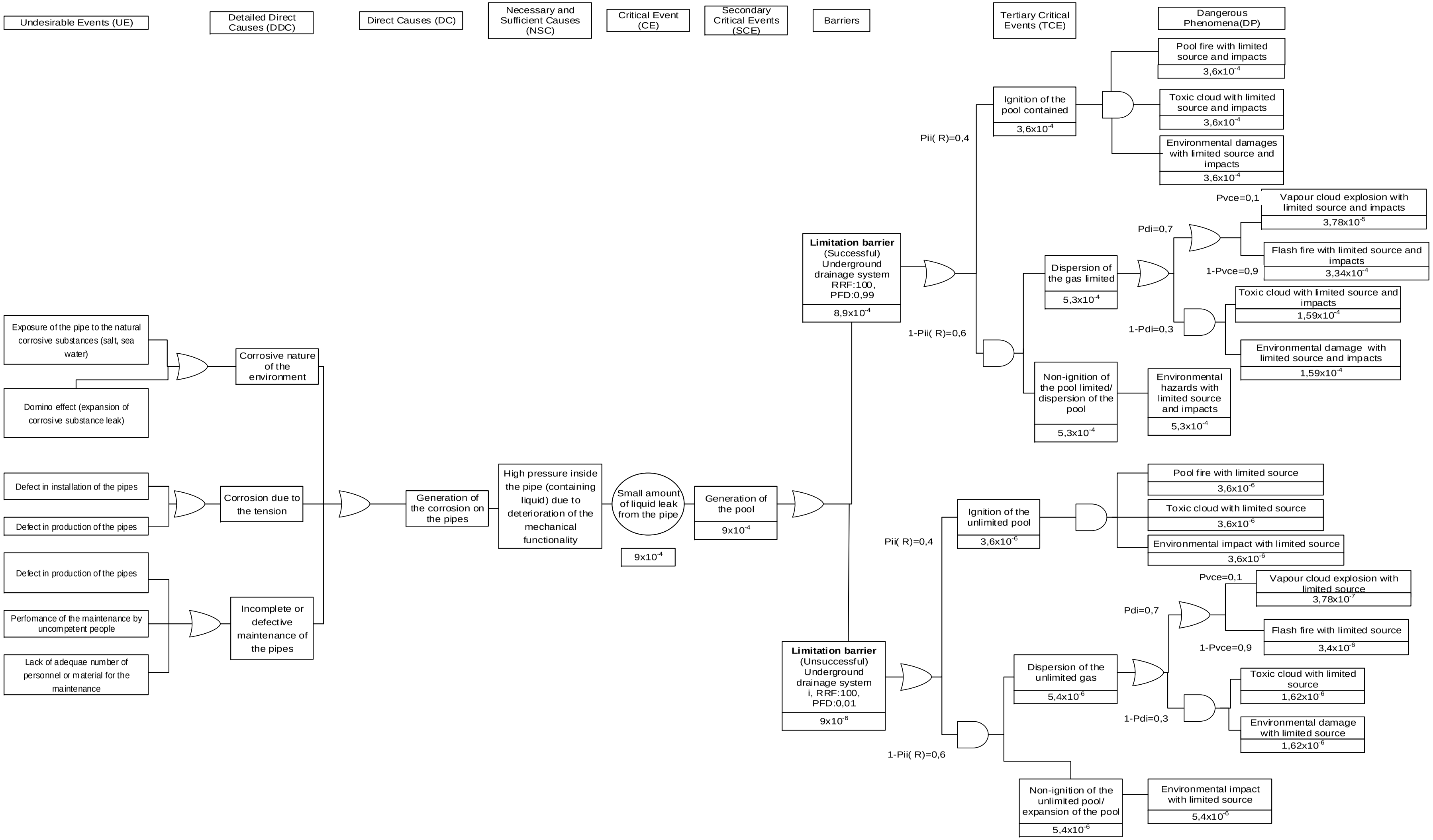

Figure 2: Partial bow-tie diagram of the critical event of small size leak in pipe line transporting heavy fuel oil from atmospheric distillation column to the scrubber column

3.3.2 Calculating the frequency of critical events and dangerous phenomena through frequency of equivalent critical events

No statistical data could be obtained from the plant in regard to the occurrence frequency of the initiating events (SINTEF, 2002). Therefore, the frequency data of respective initiating events were derived from relevant databases. However, occurrence frequency of all initiating events included in the fault tree analyses could not be obtained. Thus, considering the surveys conducted in various databases and unique characteristics of the system analysed, occurrence frequency of all critical events in entire equipment was calculated (RIVM, 2009, HSE, 2012, Delvosalle et al., 2004e, Uijt de Haag, 2004).

Using the frequency values of the critical events determined, an occurrence frequency value of the dangerous phenomena happening as a consequence of the critical events was calculated taking "AND/OR" gates into consideration (Delvosalle et al., 2004f). Thus, the fault tree analysis part of the bow-tie diagram (left hand side) remained qualitative and the event tree part of the bow-tie (right hand side) was converted into the quantitative. Probability of occurrence was determined for each critical event by assessing the event tree analysis part with and without safety barriers (Delvosalle et al., 2004g). In event tree part of critical event concerning small size of leak in said pipeline, occurrence frequency of dangerous phenomena was determined in presence of underground drain barrier with Risk Reduction Factor (RRF) of 100 and average probability of failure on demand (PFD) of 10^{-2} (PFD) (see Figure 2) (AIChE, 2001).

3.3.3 Determining class of consequences of dangerous phenomena and reference accident scenarios

Consequences of the dangerous phenomena with determined frequencies were subjected to the classification. Among the dangerous phenomena with defined frequencies and consequence class, reference accident scenarios (RAS) were chosen using a Risk Matrix. If the dangerous phenomena corresponds to the high or medium effect zone at the end of the matrix, respective dangerous phenomena was determined as reference accident scenario (RAS). For the critical event of small size leak in the pipeline transporting heavy fuel oil from the atmospheric distillation column to the scrubber column with occurrence probability of $9\ 10^{-4}\ y^{-1}$, Table 3 provides occurrence frequency of the dangerous phenomena with/without barriers, class of consequences of dangerous phenomena and risk matrix position of the dangerous phenomena. As seen in relevant table, there are six (6) reference accident scenarios (Delvosalle et al., 2004h).

Table 3: Selection of reference accident scenarios (RAS) for critical event of small size leak in pipeline transporting heavy fuel oil from the atmospheric distillation column to the scrubber column

Equipment	Dangerous phenomena	Probability of occurrence without barrier	Probability of occurrence with barrier	Class of consequence of the dangerous phenomena	Position of the dangerous phenomena in Risk Matrix
Small size of leak from the liquid phase	Pool fire	3,6 10-4	3,6 10-6	C2	Negligible
	Generation of toxic cloud due to ignition of the pool	3,6 10-4	3,6 10-6	C3	Medium impact
	Environmental damage due to ignition of the pool	3,6 10-4	3,6 10-6	C3	Medium impact
	VCE due to dispersion of the gas	3,78 10-5	3,78 10-7	C3	Negligible
	Flash fire due to dispersion of the gas	3,4 10-4	3,4 10-6	C3	Medium impact
	Toxic cloud due to the dispersion of the gas	1,62 10-4	1,62 10-6	C3	Medium impact
	Environmental damage due to the dispersion of the gas	1,62 10-4	1,62 10-6	C3	Medium impact
	Environmental damage due to dispersion of the pool	5,4 10-4	5,4 10-6	C3	Medium impact

4. Discussion and Conclusion

ARAMIS methodology requires conducting additional investigations for selection of the hazardous equipment in the event that the equipment concerned contains a substance that does not have a specific fixed boiling point. Following information was collected during the studies conducted in the study site defined in atmospheric distillation unit. In current study, majority of the events were identified either in medium impact zone (yellow zone) or in negligible impact zone (green zone) and only two events were identified for high impact zone (see Table 4). These dangerous events are toxic cloud generation due to the ignition of the pool as a result of occurrence of critical event of large size liquid leak in the pipeline transporting atmospheric bottom product and environmental damage resulting from the ignition of the leakage pool.

Table 4: Number of dangerous phenomena selected as reference accident scenarios

	Total Number
Total number of equipment within the study area identified	36
Total number of dangerous phenomena associated with entire equipment	644
Total number of dangerous phenomena considered in negligible zone (green) in risk matrix	454
Total number of dangerous phenomena considered in medium impact zone (yellow) in risk matrix	188
Total number of dangerous phenomena considered in high impact zone (red) in risk matrix	2
Number of dangerous phenomena considered as reference accident scenarios (RAS)	190

Priority should be given to the dangerous phenomena placed in high impact zone of the risk matrix. Software products such as Effect, PHAST or ALOHA may be used to illustrate the consequences of the dangerous phenomena better and to map the impacts of the dangerous phenomena on the people and the environment. Analysing the reference accident scenarios determined and the maps generated using the relevant software products, it should be attempted to move the dangerous phenomena to a safer position, i.e negligible impact zone, in risk matrix. To do this, safety barriers, having a clear impact on the class of consequence or occurrence frequency of the dangerous phenomena, should be positioned on fault tree analysis and/or event tree analysis of the dangerous phenomena. Furthermore, proof tests can apply all components in the SIS to reveal dangerous undetected failures (Yiliu, 2013). Thus, the dangerous phenomena may be moved to negligible impact zone on the risk matrix through affecting either to the frequency of occurrence of the dangerous phenomena or the class of its consequences.

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